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REPORT ON PHASE I:

EXPLORATORY INVESTIGATION OF THE NEED FOR AND FEASIBILITY OF A LOWER ATMOSPHERE RESEARCH SATELLITE (LARS) PROGRAM

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PREFACE

A Lower Atmosphere Research Satellite (LARS) Program has been identified by the Environmental Observation Division of NASA's Office of Space and Terrestrial Applications as a potential initiative. An exploratory study was started in the spring of 1980 by the Boulder, Colorado office of the Universities Space Research Association (USRA) to explore the need for and feasibility of such a new research satellite program for the intensive study of the lower atmosphere (the troposphere and lower stratosphere). The first phase of our investigation has been to explore the priorities for scientific investigation of the lower atmosphere during the next decade. The required data will, of course, come from many sources. Much already exists. More will come from ground-based programs, from operational satellite programs, and from research space experiments already being planned. A new research satellite program should be based upon the recognition both of scientific needs, and of the requirement for data that will be unavailable from other sources. Moreover, it should be regarded as one element in a broad program devoted to research on the most important scientific questions. The findings of our study to date, summarized in this report, are concerned with identification of those broad research issues of highest priority and, in particular, with those that are most appropriate for investigation from space platforms. We have not as yet attempted to look into the question of data availability from other sources, except in a superficial way. That will be the major task for the next phase of our LARS planning effort.

This summary report was prepared by Dr. M. H. Davis, based upon investigations carried out by him and by Mr. John Masterson. The study included informal discussions with a large number of atmospheric scientists. It was sponsored by the Atmospheric Sciences Division of NASA's Marshall Space Flight Center, Alabama, and includes the results of many discussions with members of that group. The recent National Academy of Sciences Report: The Atmospheric Sciences: National Objectives for the 1980's, formed the basis for the scientific inputs to this phase of the study.

We want to express our sincere appreciation to the task group leaders, both for their original discussions with us, and for their suggestions for improvements in this summary report.

TABLE OF CONTENTS

*We are following the numbering system of the NAS Report.

SCIENCE CONTEXT AND BACKGROUND

The lower atmosphere is the medium that supports all life on the earth. We are utterly dependent upon it for our survival, and our lives are profoundly influenced by its movements, by its purity, by the ways it transmits, absorbs and scatters solar radiation, and by the transformations and transport of the water substance. In recent years there has been a growing concern over the ways that human activities in an industrialized society may modify the weather, degrade air quality, and may lead to changes in climate. Research programs now focus both on understanding the processes of nature, and on understanding ways that man has become a causal agent.

All aspects of weather, both temperate and severe, impact our highly interconnected society. It is of crucial importance that the physical mechanisms involved in weather on all scales of time and space be understood to permit accurate forecasts and to allow proper assessment of the influence of human intervention, intentional and unintentional. Air quality has become a major concern at a time when it is generally realized that profound and long-lasting changes are being brought about by the increase in the CO_2 concentration in the atmosphere from fossil fuel burning; through the inadvertent introduction of chlorofluoromethane compounds into the stratosphere, with resulting changes in the absorption of radiation and catalytic destruction of ozone; by acid rain, as well as other consequences of pollution such as smog. The day when the atmosphere can restore itself to a state of pristine purity is long past.

The theory of climate has made progress in recent years toward the goal of being able to predict significant departures from "normal" climate patterns, such as droughts or cold winters. But we still have a long way to go before that goal is achieved. Better climate models are required, along with long reliable data sets and better information on the influence of such factors as pollution, volcanic activity, and solar variability.

During the past few decades worldwide research attention has focused with great intensity on the lower atmosphere. Observing networks have existed for many years that provide information on winds, temperature, pressure, and precipitation from ground based instruments and radiosondes. But information has been scanty over the oceans, the polar regions, and the tropics. To relieve this situation, many international programs have been conducted, along with special field studies sponsored by individual countries. Moreover, it was recognized before the first successful satellite launches of twenty years ago that earth-orbiting satellites could provide platforms for gathering information on the lower atmosphere, particularly by observing cloud patterns. Meteorological satellites have progressed from early R&D satellites to the present NOAA operational polar orbiting and geostationary (GOES) satellites.

In 1979, years of international planning and testing culminated in the first Global Weather Experiment of the Global Atmospheric Research Program (GARP), coordinated through the International Council of Scientific Unions (ICSU) and the World Meteorological Organization (WMO). GARP was and is a vast undertaking involving very large amounts of money, international cooperation on an unprecedented scale, and the efforts of a generation of atmospheric scientists. Its objectives are: 1) to improve the ability to forecast weather on a time scale of three to fourteen days; 2) to define the elements of a global weather observing system; and 3) to enhance knowledge of climate through the accurate specification of the state of the lower atmosphere on a global basis. It includes instrument development, data gathering through coordinated field measurements, and extensive theoretical and modeling efforts.

As a result of all the research activities and operational data that has been gathered, there is an enormous amount of information about the lower atmosphere available for study in the archives. During the next decade information will continue

to pour in from ground-based networks, from operational satellite programs, and from a few research space experiments. The need for coordinated field efforts is well recognized, and new information is being gained and will be generated by programs such as GARP, NASA's Atmospheric Variability Experiment (AVE), the Severe Environmental Storm and Mesoscale Experiment (SESAME), and the Cooperative Convective Precipitation Experiment (CCOPE) that is planned for 1981.

The role of a Lower atmosphere Research Satellite (LARS) Program would be to provide atmospheric scientists with a research space platform which could provide wide-area coverage for sensors to carry out many types of observations of the lower atmosphere that would be difficult or impossible from the ground, and provide data not available from operational satellite systems or from other planned space experiments. If the Upper Atmosphere Research Satellite (UARS) Program becomes a reality, LARS, though concentrating on the lower atmosphere, would complete the research coverage of the earth's atmosphere.

The LARS planning effort is still in the exploratory stage. We are attempting to discover whether or not a need is recognized by the community of atmospheric scientists for a research satellite system to augment the data that is already available and that will be obtained from other programs: ground-based, operational satellites, Space Shuttle experiments and other space research projects. USRA, under sponsorship by NASA's Marshall Space Flight Center, has carried out a low-key investigation for the past six months. The body of this report summarizes our findings to date.

We have drawn extensively from the National Academy of Sciences Report: The Atmospheric Sciences: National Objectives for the 1980's, by the Committee on Atmospheric Sciences of the National Research Council, National Academy of Sciences, 1980. A draft of the report was kindly made available to us prior to publication by Mr. John Sievers, and Dr. Cecil E. Leith, Jr. The report has now been published and is available from the Academy. We usually refer to this as the "NAS Report".

During the first phase of our exploratory study, we talked to each one of the National Academy of Sciences task group leaders, along with a number of their colleagues. The final section of this report summarizes the findings of the task groups, along with our discussions with individual scientists, from the standpoint of the LARS planning effort. It is based upon notes and interpretations by Davis and Masterson.

In the course of the present study, a number of documents were consulted. These included:

Upper Atmosphere Research Satellite Program, Final Report of the Science Working Group, July 15, 1978. JPL, Pasadena, California (JPL Publication 78-54).(UARS)

Geosynchronous Earth-Atmosphere Research Satellite (GEARS) Report Resulting from the First Meeting of the Ad Hoc Science Working Group, NASA/GSFC, July 31, 1980.

Proposed NASA Contribution to the Climate Program, NASA, July, 1977.

NASA Tropospheric Program Plan (DRAFT), Working Group on Tropospheric Planning, NASA/LaRC, April, 1980.

Solar-Terrestrial Observatory Science Study Group, Final Report, in process of publication by NASA/MSFC, 1980.

And, as already cited,

The Atmospheric Sciences: National Objectives for the 1980's, Committee on Atmospheric Sciences, Assembly of Mathematical and Physical Sciences, National Research Council; National Academy of Sciences, Washington, D.C., 1980.

THE LARS CONCEPT

The basic concept of a Lower Atmosphere Research Satellite (LARS) System is of a satellite or series of satellites to carry sensors, together with associated theoretical and modeling efforts, ground-based data gathering and studies within the atmosphere, that would complement the proposed Upper Atmosphere Research Satellite (UARS) Program by specifically concentrating research attention on the troposphere and lower stratosphere, and would serve as the research adjunct to the operational meteorological satellite programs of NOAA. The time-frame being considered is the late 1980's.

As a research satellite system, LARS would not bring on the programmatic problems often encountered when research experiments "piggy-back" on operational satellites. An operational satellite is no longer controlled by NASA or the research scientists associated with the experiment and its sensor systems. It has a specific mission to perform, and if a conflict arises between that mission and a research experiment that is riding along, of necessity the operational mission requirements take precedence.

UARS and LARS together would provide a comprehensive picture of atmospheric processes from the earth's surface up through the thermosphere. The real motivation for LARS, however, comes about from a recognition of the research needs for improved information about processes in the lower atmosphere by specialists in the fields of meteorology and climate science. As a complement to operational meteorological satellite systems, LARS would serve to fill in research gaps, cross new frontiers, and demonstrate new remote sensing techniques not currently available. LARS could serve as a testing ground for new experimental concepts that eventually would be incorporated into operational systems and that require longer operating times or a different orbit than provided by the Space Shuttle. The LARS concept could include long duration missions and the acquisition of long consistent data sets might be

undertaken in the context of a research satellite program.

The specific question that needs to be answered is whether there is a recognizable need for a new research satellite system and program to supplement the data already acquired and anticipated during the next decade or so. For the answer to be "yes", there must exist research areas of high national priority that require data that is unavailable from sources already in existence or planned. We must also determine that required priority data can be best gathered by sensors on an orbiting platform.

The next stage in planning will be to look in detail at the research data requirements, and particularly at what is already available in the archives, and what can be expected from other programs, such as ground-based programs, operational satellite systems, and planned space experiments. For the data that appears to be best gathered by a new research satellite program, we will begin to look in detail at possible experiments, sensors, data requirements, orbits, and other technical factors.

PRIORITY RESEARCH ISSUES FOR THE LOWER ATMOSPHERE IN THE COMING DECADE

In outline form, the highest priority research issues according to the NAS Report are:

1) Weather Prediction

a) local short-range prediction of severe weather.
b) better understanding of precipitation.
c) better prediction on the scale of cyclones and frontal systems.

2) Climate

a) determine the response of climate to changes in conditions at the earth's surface.

b) determine the feasibility of predicting climatic anomalies a month or more in advance.

3) Atmospheric Chemistry

a) study the interaction of chemical and meteorological processes, including transport, chemical conversion, rainout and washout.

b) study the bioatmospheric cycles to provide a scientific foundation for preventing or minimizing the harmful atmospheric effects of human activity.

c) study distributions of trace gases and aerosols, particularly those that appear to influence global and regional climate.

Background material is presented on these high priority research issues in the final long section of this report, where the NAS Report is discussed at length, along with summaries of our discussions with the task group leaders.

PRELIMINARY CONCLUSIONS FOR THE LARS PROGRAM

Many of the scientists we have talked with have emphasized the need to make effective use of the enormous amount of data on the lower atmosphere, from satellites and from ground-based systems, that already exists through all the efforts over the past decades including those that culminated in the GARP Global Weather Experiment. For some purposes new satellite information is not needed nearly so much as in-depth analysis of data that either exists or is currently planned from operational systems. For LARS, the question is whether there are research areas that require new data acquisition that would benefit from satellite technology. From the NAS Report, and from our discussions with its authors, we conclude that the answer to this question is a definite yes. A number of research issues would benefit greatly from new types of data and research satellite platforms could play a key role. (At this stage in our investigation we are not ready to say which of these areas may be already covered by operational satellite programs or in other ways.)

A) Candidate experiment classes for LARS -- a sampling

1) Global and regional cloud studies

Since clouds play a crucial role in precipitation, scavenging processes, and the earth's radiation budget, many scientists we have talked to have stressed the need for global and regional surveys of clouds, including as much about their characteristics as can be obtained by remote sensing: ice/water, particle spectra, liquid water content, height of cloud top, temperature, radiation, precipitation, etc. (Not all of these are accessible to remote sensing using presently known techniques.) Information on all cloud types is needed: stratus and cirrus along with cumulus. Information is needed at all seasons, all types of weather situations, and for the entire globe.

2) Surveys of aerosols, haze and fog

Aerosols affect the earth's climate through absorption and scattering of radiation. Aerosol particles also serve as nucleating agents for water phase changes: vapor-to-liquid, and liquid-to-ice. Haze and fog modify atmospheric radiative properties and also influence local climate. Studies of fog are of considerable economic importance, since fog seriously affects aircraft operations, ship movements, and other transportation elements through limiting visibility.

3) Regional and global precipitation surveys

Mentioned above under (1), but worthy of a separate category are studies of precipitation, since understanding of precipitation and achieving improvements in its prediction are recognized as goals of the highest priority for the coming time period. A related goal is to better assess the contribution of latent heat to the atmospheric heat budget.

4) Monitoring of CO_2 and O_3

Carbon dioxide, particularly, will require long-term highly accurate monitoring for assessment of the climate impact of its gradual increase in the earth's atmosphere. Ozone studies impact climate as well as possible solar-terrestrial coupling mechanisms.

5) Monitoring of other trace gases

The chlorofluoromethanes absorb strongly in the infrared as do certain other trace gases. CFM's also cause catalytic destruction of O_3 and so potentially affect stratospheric chemistry in an important way. Other pollutants of importance include NO_x, SO_2, and many other species listed in the section on Atmospheric Chemistry of the NAS Report.

6) Observations of the earth's surface for climate studies

Data relating to soil moisture, the role of vegetation in moisture exchange at the earth's surface, moisture and temperature exchange at the air-sea interface, ice cover, and many other surface parameters are needed to establish the lower boundary condition. Some of these are measurable in principle by satellite-borne sensors. Others either are not, or require new ideas (e.g. how do you measure soil moisture in the root zone?)

7) Mesoscale observations

Since much of the earth's severe weather is produced by mesoscale and storm-scale convection, research efforts should concentrate on understanding the conditions that bring about strong convection in the atmosphere, along with all aspects of severe storm development. Satellite observations can contribute markedly to such a research program, particularly if a dedicated geosynchronous satellite system is available.

An important potential use for satellite technology would be the determination of cloud-top height, and cloud top topography through stereo techniques. This could be achieved through several geosynchronous satellites in consort, or possibly through processing successive images from a lower altitude satellite.

8) Tropospheric winds

Atmospheric dynamicists agree that direct determination of the tropospheric wind field would be of great value to them. Research on the feasibility of satellite-borne doppler lidar systems for global wind measurements is proceeding at NASA/MSFC and at NOAA/WPL. There may be a role for LARS in the development of this system, or even in its implementation in a research context.

9) Remote sensing of pollution plumes

What appears to be needed is a way to monitor pollution

gases and aerosols from source to eventual removal, probably through a combination of measurements of winds and chemical constituents. It would be very desirable to accomplish this task from a satellite platform, although it is not clear that all of the necessary measurements can be made remotely. Probably satellite observations will be used to augment what is basically a ground-based program using instruments on the surface plus aircraft.

B) Types of observations -- missions

1) Global or wide geographical area coverage

One of the research applications for satellite technology frequently stressed in our discussions with scientists was global coverage: of clouds, radiation, lightning, ...

2) Ability to respond to particular events or times

If a satellite is in the right location (geosynchronous, perhaps) then it could "zero in" on a particular severe storm system and provide detailed information. This is one example of the capability under consideration. Another similar potential would be to have instruments standing by to make a variety of coordinated measurements if a very large solar proton event were to occur, or if a volcano were to erupt. In this case the satellite provides again the ability to always be at the right place at the right time.

3) Monitoring of particular phenomena or particular locations

Satellite technology can provide the ability to monitor events in the lower atmosphere in situations where this cannot be accomplished using ground-based instruments because the geographical extent is large, because of political considerations, or for some other reason.

4) Measurement of meteorological quantities in inaccessible regions of the earth

Examples are the tropics, poles and the ocean-areas of the earth. This application is also one where research satellite data-gathering and communication in conjunction with ground-based unmanned instrument packages would be important to consider.

5) Test and check-out of instrument and experiment concepts that may eventually be used in operational systems

The research satellite can provide the necessary platform for the test and check-out of new and improved instruments and concepts for eventual use in operational satellite systems in cases where for some reason Space Shuttle experiments would not be effective.

6) Experiments that are complementary to operational satellite systems

One important example would be to use LARS to provide a continuous absolute calibration for some set of relative measurements provided by sensors carried by an operational satellite.

C) Instrument classes--- a sampling

1) Imaging devices

Imaging techniques have been highly developed to provide quantitative maps of clouds in the visible, infrared, and microwave regions of the spectrum, in atmospheric "windows", as well as viewing water vapor distributions, and the earth's surface. Coverage may be broad or detailed. Another interesting possibility is to use stereographic techniques to obtain three-dimensional information.

2) Temperature and moisture profiles

Passive spectroscopic sounding techniques are under development to provide temperature and moisture vertical profiles. Learning to use this satellite-generated data has been a problem since it differs both in accuracy and in coverage from the familiar radiosonde data.

3) Passive radiometry

Microwave radiometry for precipitation measurements; infrared for the earth's radiation budget, cloud temperatures, surface temperatures.

4) Solar occultation

Spectroscopic measurements of trace gases, aerosol scattering, in the lower stratosphere.

5) Active radar

For studies of precipitation, motions within clouds, cloud structure. Serious problems exist due to power and weight requirments.

6) Very narrow band spectroscopy

Very narrow band spectroscopy might be useful for monitoring particular trace gases in pollution plumes.

7) Lidar

Doppler lidar methods are being explored for satellite use in determining the wind-field of tropospheric winds (two-dimensional). Such a system would also be very useful in monitoring tropospheric aerosols.

8) Lightning detection, regional and worldwide

Detection of lightning worldwide and in particular geographical regions is an application of satellite technology that would have considerable economic benefits to power companies, and to many other users. Lightning detection may have an important application for severe storm warning, although more information needs to be developed before this potential can be fully assessed. Both optical and radio detection methods are under study. LARS may have a role, either as a testing ground, or as a carrier for research experiments.

D) Orbit considerations

From the standpoint of the NASA planner, the question of the required orbit for a research satellite or platform is critical. The orbit altitude (or, more accurately, the semi-major axis) that is attainable is limited by the available propulsion energy. The orbit inclination is constrained by the launch site as well as by energy considerations if inclination changes in flight are contemplated. There is no attempt here to discuss all of the factors that lead to the choice of orbit, but rather some characteristics are discussed as they relate to the potential for lower atmosphere research from space.

1) Geosynchronous

The geosynchronous orbit, an equatorial orbit whose altitude above the earth's surface is such that the satellite makes one orbit per day in the same direction that the earth turns on its axis, has been employed for a number of years for research and operational satellites used to observe the lower atmosphere. Sensors on a geosynchronous satellite can observe the same geographical region continuously, since the satellite remains nearly stationary with respect to the subsatellite point on the earth's surface and there is a constant viewing geometry with respect to other points within the observable cone of angles. Spin stabilization has been employed since three-axis stabilization requires expenditure of power or gas. Quasi-global coverage can be achieved only through a collection of geosynchronous satellites distributed around the equator. High latitude (greater than 70^{o}) regions are not accessible, and ground resolution may be limited by the great distance of the satellite. Weight and power limitations imposed by launch requirements are other constraints.

2) Low earth orbit -- sun synchronous

Normally the orbit plane of an earth satellite precesses with respect to the earth-sun line, so the satellite passage over earth locations passes through all local times. However, there is a particular choice of orbit plane inclination with the earth's equitorial plane such that this relative motion does not occur. (For 600 km altitude circular orbit, this is about 98^{o}, which means that the Western Test Range would have to be used for launch.) For some experiments a sun-synchronous orbit would be desirable; for example, for continuous monitoring of some aspect of solar radiation. But in many cases the experimenter will want to choose an orbit that will precess with respect to the earth-sun line

in order to obtain data for all local times.

3) Low earth orbit -- all sun angles

For a circular orbit at 600 km altitude, an orbital inclination of 56°, the maximum that is attainable from the Eastern Test Range, will precess through all local times at the equator in about 36 days.

4) Low earth orbit -- polar

As already pointed out, for orbital inclinations greater than 56° it will be necessary to make use of the Western Test Range for launch. It is possible to change orbit inclination by a correction in flight, but energy requirements are a constraint. High inclination orbits are required for coverage of the polar regions.

5) Low earth orbit -- low inclination ("equatorial")

The minimum orbital inclination for launches from the Eastern Test Range is 28.5° though the possibility exists for orbital plane changes in flight given adequate propulsion. The earth's equatorial regions have been stressed by many of the scientists we have talked to as particularly important for tropospheric research during the next decade.

6) Other considerations

The effect of air drag in limiting the lifetime of a satellite in orbit is an important consideration. Although for most purposes circular orbits are preferred, special eccentric orbits can also be considered for special purposes.

E) Research versus operational satellites

For operational satellite systems, the operational mission must take first priority. So, although there are often cost savings in having a research experiment "piggy-back" on an operational satellite, there are also disadvantages to the research scientist. A research satellite platform would provide the needed flexibility and give the scientists primary control.

The operational satellite systems provide the background data required for many of the research questions discussed in this report. However, there are problems in using operational data for research purposes. An example is the requirement for redetermination of satellite altitude and conversion from satellite-scan coordinates to earth-located coordinates that has often been necessary. Such reprocessing is costly in manpower and computer time.

A Lower Atmosphere Research Satellite system could well serve as a test bed for proof-of-concept for new instruments, and for instrument improvement and check-out. The Space Shuttle will also provide a platform for instrument development, but its limited lifetime and restricted orbit may limit its utility for this purpose in some cases.

In many ways a LARS system would be complementary to the operational satellites of the next decade. It would serve as a testing ground for new instruments, it would provide research augmentation, and calibration. Similarly, the operational satellite systems would provide the much-needed background information on the state of the lower atmosphere, and the surface of the earth.

MATERIAL BASED UPON THE NATIONAL ACADEMY OF SCIENCES REPORT AND UPON DISCUSSIONS WITH TASK GROUP LEADERS

The selection of material and emphasis in the following sections was based upon consideration of topics that apply to the uses of satellites and orbiting platforms and so would be relevant to the LARS planning effort. Some of our discussions were direct conferences with the individuals, others were by telephone. In all cases, informality was a key element, and lapses in accuracy or emphasis are the responsibility of the author of this report, not the task group leaders and their colleagues, who have not yet had an opportunity to make corrections. Each section gives a summary both of the material in the NAS Report, and of our conversation with the task group leader and colleagues.

1) Impacts of Weather and Climate on Society.

Robert G. Fleagle, University of Washington, Leader

The report of this workshop task group gives an overview stressing matters of political and scientific policy. Our conversation with Dr. Fleagle, on the other hand, ranged over many specific topics. When asked to suggest the most important research areas as he saw them, in the context of the LARS study, Fleagle suggested the following topics:

1) a definitive study of radiation balance for the planet,

2) a comprehensive program of ocean surface observations; sea-surface temperatures, wind-stress, currents;

3) comprehensive study of air pollution, particularly the long range transport of pollutants.

4) an accurate way to include cloudiness in climate models,

5) global surveillance of soil moisture, and vegetation.

The ERBE experiment planned for the mid-decade may handle (1), and the NOSS satellite is designed to provide the data called for in (2). Air pollution studies, and particularly the transport of pollutants were mentioned by many of the people we talked with.

There was general agreement that measurements of air flows and direct detection of pollutants would be important, and that satellite observations could be of great value, particularly for pollutants with long lifetimes.

Better statistical information on cloudiness and on cloud types would lead to better ways of including cloudiness in climate models. Besides this, there is a need for better ways to include the contribution of clouds, both solid cloud decks and collections of clouds with open spaces in between, in climate models. This sounds like a closely coordinated program of satellite observations, radiation measurements, radiative transfer theory and modeling studies.

2) Short-Term Forecasting and Services

Verner E. Suomi, University of Wisconsin, Leader

The task group on short-range forecasting emphasized the need to develop ways to make the best possible use of the vast quantity of sensor data on the lower atmosphere that will be available in the 1980's. They particularly point to the importance of interactive computer techniques and new software developments. The great need is to devise efficient ways to distill useful meteorological information from the data, both from ground-based stations and from satellite sensors. The report states: "This distillation of meaningful information from the almost incomprehensible amount of data will make the nowcasting problem tractable." Besides the ability to make accurate short-term forecasts, there is a requirement to improve the distribution of this information to the members of the public and others who need it, both in a timely fashion, and in a form such that they can make the best use of it.

Our discussion with Dr. Suomi covered many topics. He believes that the possibility of a research satellite system dedicated to the lower atmosphere opens up many interesting possibilities to fill in gaps in knowledge of atmospheric processes on all time scales. He emphasized the importance of improved understanding of the transport of water vapor and the water substance in the atmosphere, along with the interactions of the atmosphere with the oceans. He also stressed the importance of research on the atmosphere in the tropics, where current data of sufficient accuracy is scanty.

Specific ideas for satellite research: a) a cluster of geostationary satellites to permit stereo measurements of clouds and of water vapor distributions; b) a low-altitude low-inclination satellite, specifically for studying the atmosphere over the tropics.

We concluded from the task group report and our discussions with Suomi and coworkers that the need in the next decade in the area of short-range forecasting is not for new data-gathering systems, but rather for better analysis and dissemination methods. However, a research satellite system would be of value in providing better data on cloud structure and water vapor distribution and transport in the atmosphere through stereographic or other techniques, and to provide enhanced coverage of meteorological parameters in the tropical regions.

3) Mesoscale and Synoptic-scale Forecasts

Cecil E. Leith, Jr., National Center for Atmospheric Research, Leader

There is a significant gap between the predictive skill that might reasonably be expected for mesoscale weather processes from present observational networks and what is currently being achieved. Reliable prediction of small-scale precipitation: amounts, location, onset time, duration, type, is particularly difficult. And this includes most destructive severe weather -- flash flooding, tornados, blizzards, etc.

The task group put highest priority on the study of the mesoscale structure of extratropical cyclones, with emphasis on moist thermodynamic and precipitation processes. In addition, the task group recommended concentrated study of the mechanisms by which sub-synoptic scales in the atmosphere induce the outbreak of severe convective storms, along with further development of statistical relations between larger-scale variables used in numerical models and smaller-scale weather phenomena. The best chance for elucidating the mechanisms involved will come through simultaneous measurements of sub-synoptic variables at times when convective storms are likely to occur. Much of the research suggested will involve using existing data sets and data that is expected from existing and planned operational systems, rather than new instrumentation or new systems for data gathering.

In our conversation with Dr. Leith, he expressed great enthusiasm about the prospects for direct data on atmospheric winds such as will be gathered from the proposed satellite-borne lidar systems proposed for the latter part of the decade. Winds now are almost entirely derived from temperature soundings. The problem is that temperature soundings available from operational satellite data are less accurate than required, and their use in computer models has been disappointing (though part of the problem may be in the algorithms used.) There appears to be

general agreement among the scientists with whom we have talked that direct measurement of tropospheric wind fields to an accuracy of around 1 m/s, which is now being contemplated for 300 km X 300 km areas and 1 hour averages, would represent a significant advance in knowledge of the state of the atmosphere and would lead to improved global modeling.

Dr. Leith stressed the importance of improved information on water transport in the atmosphere: precipitation, water vapor transport, transpiration and evaporation at the earth's surface. Knowledge is deficient, particularly for the equatorial regions of the earth. He also noted that the next decade will see increased emphasis on studies relating to climate change. Key elements will be studies of radiation from clouds, and studies of the interactions between the atmosphere and the oceans. In both of these research areas, satellite observations will play a decisive role.

Important applications of satellite technology include coordinated observations from satellites and ground-based sensors of the mesoscale conditions that give rise to strong convection and resulting severe weather. It might well take a dedicated satellite system to make such observations possible, though data from operational satellite systems might be adequate. New instrument development is required for the proposed satellite-borne lidar systems to measure tropospheric wind fields, and to measure water vapor transport and evaporation at the earth's surface. Soil moisture is also an important parameter that may be measurable by satellite sensors.* Proper handling of radiation in climate models, particularly from clouds and cloudy fields in the atmosphere, is seen as a key element in the improvement of climate modeling. During the next decade, emphasis should be placed on satellite measurements of the earth's radiation budget, such as the ERBE program, and in statistical studies leading to a cloud climatology -- which may not imply new measurements, but might be accomplished using existing data.

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*This is an important area for ground-based sensors, both for data gathering and ground truth.

4) Seasonal and Interannual Climate Predictions

John M. Wallace, University of Washington, Leader

The climatic time periods considered by this task group are those longer than the lifetime of typical weather systems, but shorter than those of the usual climatic averages. Included are such long-lived systems as blocking highs, seasonal anomalies resulting in droughts or cold winters, anomalies that reoccur several times during a decade.

The physical mechanisms responsible for variability on these time scales are not well understood, but presumably involve interactions between the atmosphere and the stratosphere or the surface, both of which could provide the required long "memory time." Other factors are volcanic activity and solar variations. The major tasks seen for the next decade are to attempt to understand the dominant causal factors, and to assess the feasibility of prediction of atmospheric behavior on this time scale. The task group stressed the need to utilize fully the existing data sets and to maintain insofar as possible the worldwide measurement network already established. It also emphasized the importance of the NASA Earth Radiation Budget Experiment (ERBE). A large number of more specific research suggestions appear in the NAS Report.

In our discussion with Dr. Wallace, he pointed out that data already in existence is not being used to the fullest. Real problems exist in deriving the needed climate information, partly due to the costs of the manpower and computer time involved. The research needs of climate scientists might be better served by archiving condensed data sets or properly designed statistics.

New satellite technology has the potential of giving useful information about soil moisture, of providing direct wind measurements, of supplying comprehensive data on cloudiness and precipitation, and of supplying much-needed meteorological and climatological data on the tropics. Wallace also mentioned the need for effective ways to handle the effect of changes in cloud cover on the earth's radiation balance.

5) Long-Range Climate Change

Andrew P. Ingersoll, California Institute of Technology, Leader

The broad research topics selected for emphasis by Task Group 5 were: 1) Global or hemispheric temperature changes associated with radiative forcing due to changes in global aerosols, solar variations; 2) Regional low-frequency atmospheric phenomena suspected of being driven by changes in surface conditions; changes in sea-surface temperatures, sea ice, and snow cover, urbanization and agriculture. Also high-frequency phenomena that have influences at low frequencies. 3) Subsurface processes such as the oceanic mixed layer, soil moisture and vegetation, sea ice and snow cover.

Dr. Ingersoll pointed out in our conversation with him that operational satellite systems usually are not capable of absolute measurements, their sensors are calibrated only for relative measurements. For absolute determination of atmospheric quantities, there needs to be calibration by rockets, aircraft, research satellites, or, where appropriate, by ground truth measurements. He stressed the value of being able to measure many parameters simultaneously: infrared emission + cloud cover + stratospheric and tropospheric gases + moisture and soil parameters.

An important unknown in the global energy balance is the latent heat release term. The problem of sampling makes this particularly difficult to obtain.

One important use for an experimental satellite would be to test out concepts for instruments that might eventually go on operational satellites. Examples would be instruments to measure soil moisture, vegetation, and the transpiration and evaporation of water vapor from the earth's surface. Someday there will undoubtedly be a global climate experiment, and we need to plan now, and develop instruments, techniques, and models.

6) Advertent Weather Modification

Charles L. Hosler, Jr., Pennsylvania State University, Leader

One of the major recommendations of this subgroup was for a concentrated research effort in the overlapping area between cloud microphysics and cloud dynamics as a basis for improvement of understanding clouds and their response to modification efforts. There would be an important role for satellite observations in such a study through the gathering together of a systematic census of cloud and cloud-environment characteristics over various geographical, seasonal and climatic regions. Also needed are means for remote sensing of cloud particle spectra, detection of ice in clouds, and measurement of motion fields in three dimensions.

Dr. Hosler pointed out in private conversation that any factors that change the onset time of cloudiness or the duration of clouds by only a few minutes would act to change the energy balance in the earth's atmosphere through radiation and through latent heat release by amounts comparable with those that are attributable to increases in the concentration of CO_2 in the atmosphere that are of present concern to climate scientists. Such modifications could arise from many influences: pollution effects changing the nucleation efficiency for either condensation or freezing, solar-terrestrial influences that might affect cloudiness, regional changes in water evaporation and transpiration at the ground. There is clearly a need for better understanding of the role of cloud development in larger atmospheric processes and energy balance.

7a) Inadvertent Weather and Climate Modification

George D. Robinson, Center for the Environment and Man, Leader

The most important way that human activity may influence global climate is believed to be through the effects of CO_2 and other gases with strong absorption bands in the infrared (such as CO and O_3). Other gases that strongly absorb in this region are the chlorofluoromethanes, which have a long lifetime in the stratosphere. Of all these, CO_2 appears to have the greatest impact, though predictions of the climatic consequences of the increasing CO_2 concentration in the atmosphere are conflicting.

Other weather and climate effects discussed by the task group included man-made land-use changes such as deforestation and urbanization. The task group was also concerned about the weather and climate effects of combustion products other than CO_2, such as sulfur compounds and particles, both of which presumably affect cloud microstructure and atmospheric radiative properties.

In private conversation with Dr. Robinson he stressed that the first indications of changes in atmospheric temperature brought about by CO_2 might be detectable in the stratosphere. The problem with detecting small changes over long periods of time by operational satellite systems is that they are not designed to make absolute measurements.

From the standpoint of global climate, relatively subtle changes only detectable over long time periods could be important. Haze, for example, tends to smooth out temperature fluctuations. Something that could change the agricultural growing season by a week or so, though insignificant in terms of overall energy balance, could have long-term cumulative effects on soil conditions, moisture, and ultimately on regional climate. Satellite sensors should be able to monitor haze distribution. Pollution plumes should also be studied in the climate modification context, since clouds downwind of cities may be modified (this is still an open question).

7b) Atmospheric Chemistry

Paul J. Crutzen, National Center for Atmospheric Research, Leader

The research field of atmospheric chemistry was identified by the NAS Workshop as one of the major high priority research areas for study during the 1980's. This high priority reflects both the urgency of increasing man's understanding of processes that introduce trace gases into the atmosphere and remove them, and the present lack of full understanding of many aspects of these processes.

Man's activities put a tremendous variety of chemical substances into the atmosphere. Many then undergo changes, form new compounds, and change form under the influence of other chemicals, solar radiation, and interactions with hydrometeors. Some persist for long time periods. Changes are produced in the chemistry of precipitation, the radiation balance (particularly from CO_2 increases), the natural atmospheric chemical processes (viz. catalytic destruction of O_3 by chlorofluoromethanes), and in the natural atmospheric aerosol population (viz. conversion of SO_2 to liquid H_2SO_4 droplets). It is often very difficult to follow the various species from source to sink through the many complex chemical reactions that may occur during transit. Significant concentrations are often extremely low. The NAS Report states that the catalytic efficiency of ClO radicals in ozone destruction is so great that in the upper atmosphere only 1 part per billion is significant. The radiative effects of similar concentrations can also play an important role in atmospheric heating and cooling.

Specific recommendations include: observations of the chemical composition of the atmosphere over all regions of the globe, under all weather and seasonal conditions, in widely different areas -- urban, maritime, equitorial, polar; in the troposphere and in the upper atmosphere. Global monitoring at all scales will be required for the trace gases known to be active, such as NO_x, CO, CO_2, CFM's, as well as searches for undetected species. Chemical transformation studies are required, both field experiments

and laboratory studies. Research is needed on the chemical interactions among the biosphere, hydrosphere, and atmosphere: emissions and uptake of gases and particles. In addition, much more information is required on the migration and transport of atmospheric chemicals. Obtaining this information will require close cooperation between meteorologists and atmospheric chemists.

Dr. Crutzen, and his colleagues, Alan Lazrus, and Patrick Zimmerman, all stressed the need for global surveys and for the monitoring of key trace gases in the atmosphere. Most important for climate effects is CO_2, with oxides of nitrogen and O_3 also very important. Many other trace gases would be interesting to measure, though many can be effectively monitored from ground stations. Examples are COS and chlorofluoromethanes. It would be particularly important to trace pollutants from their sources to their eventual dissipation or removal. Satellite platforms would be particularly effective in studies of CO_2, CO, NO_x, and aerosols such as H_2SO_4 droplets.

The atmosphere is chemically especially active in the tropics, and this is the region of greatest importance to monitor carefully. Zimmerman stressed the need for good surveys of land usage, particularly deforestation and drainage of wet areas. Methane is an important trace gas to monitor because it contributes to stratospheric hydrogen and indirectly influences the chemistry of CO and OH.

We conclude that atmospheric chemistry will receive very increased support during the next decade. Satellites may contribute significantly to global monitoring of such gases as CO_2 and O_3, as well as NH_3, CH_4, COS, and CH_3Cl. Other "exotic" trace radicals and compounds probably are best investigated from ground-based and airborne platforms, though satellite potential for aerosol measurments should be fully exploited. Logistics problems in tropical regions could make

satellite data gathering from ground stations an attractive possibility. A very important research effort will be in the tracing of pollution plumes from their source to their eventual dissipation, along with studies of the related microscale and mesoscale meteorological environments.

8) Cloud Processes

G. Brant Foote, National Center for Atmospheric Research, Leader

Cloud processes impact nearly all aspects of atmospheric science: precipitation, atmospheric chemistry, radiation, climate, severe weather. Task Group 8 identified as the research problems of highest priority: 1) Study of convective clouds through combined theoretical and field investigations. (Small cumuli and stratiform clouds also need greater attention than they have been given in recent years.) 2) Studies of the composition of clouds; types, sizes, number density of hydrometeors; spatial and temporal distributions. 3) Development, standardization and calibration of instruments for determining cloud properties under (2). 4) Studies of the role of clouds in "wet" scavenging of trace gases and particles. 5) Studies of the interactions between cloud electricity and cloud dynamics and evolution; charging mechanisms.

The importance of better understanding of ice processes in clouds was stressed, since although they are known to be the controlling factor in the production of precipitation in many clouds, many questions remain unanswered, and the basic physics remains poorly understood. The composition of clouds strongly affects their radiative properties, so better information will lead both to better ways of including clouds in climate models, and to better utilization of remote sensing, using radiative techniques.

A survey of clouds and precipitation is needed over large geographical areas and eventually over the entire globe.

Dr. Foote and Dr. Patrick Squires stressed the need for more comprehensive data on mesoscale weather phenomena, which is the scale of most severe weather. One type of measurement Foote suggested would be of great value would be cloud-top topography with about 1 minute -- 1 km resolution, in order to better describe storm evolution. Such satellite measurements would also give better boundary conditions for ground-based doppler radar measurements. Cloud top heights, related to the first appearance of radar echos from coordinated ground-based radars, would be an important element in better understanding precipitation mechanisms.

9) Atmospheric Dynamics

James R. Holton, University of Washington, Leader

Since the research field of atmospheric dynamics covers fluid motions of the atmosphere on all time and space scales, the remarks of this task group cut across a number of areas covered also by other task groups on the NAS team. On the planetary scale, the task group recommends a comprehensive program to study planetary waves. In particular, the need was stressed for better understanding of forced planetary scale disturbances that result in "blocking" patterns that produce presistent anomalous weather over large regions. We need to understand better how such patterns are established and maintained, and how forcing by topography and by land-sea heating contrasts takes place. The need for better understanding of stratospheric ozone was stressed, particularly because of the climatic effects of ozone changes.

Climate modeling is recognized as one of the highest priority research fields for the next decade. Gaps in current knowledge include how to handle cloudiness adequately, radiative effects, and the inclusion of air-sea interaction. Other uncertainties are surface interactions involving evaporation at the surface and the effects of vegetation.

On the mesoscale, the need for better understanding and prediction of severe storm activity was stressed. What are the conditions that give rise to strong convective storms? Progress in three-dimensional numerical modeling was cited as particularly encouraging in predicting some of the most important features of severe storm processes.

In our conversation with Dr. Holton he remarked that winds are the most important atmospheric quantity to the dynamicist. This is particularly true for the tropics. He also stressed the need for coordinated mesoscale research to improve understanding of atmospheric processes on the cyclone and storm scales.

10) Boundary-Layer Processes

John C. Wyngaard, National Center for Atmospheric Research, Leader

The boundary layer is the part of the atmosphere that we actualy live in and that makes contact with the earth's surface. All moisture passes through the boundary layer; it is where pollution arises. Air-land and air-sea interactions are boundary layer processes.

The highest priority tasks for the next decade that were identified by the task group are: 1) further development of turbulence parameterization and 2) development of new methods for sensing planetary boundary layer structure. Satellite measurements may contribute to the second of these tasks through remote sensing techniques, and through data gathering and communication with ground-based in situ measurement packages.

In our talk with Dr. Wyngaard, he stressed the need for new techniques to obtain the data needed on boundary-layer processes. One possibility to be explored is that satellite observations of cloud structure might lead to improved statistics of surface moisture flux into the atmosphere.

The problems of atmospheric pollution are of great national importance, and are complicated by their multidisciplinary nature. Cloud studies are an important ingredient, since clouds are actively involved in pollutant transport, modification, and removal. Satellite contributions to cloud studies have already been stressed in this report.

11) Atmospheric Radiation

James Weinman, University of Wisconsin, Leader

Radiation from the atmosphere itself, radiative transfer processes within the atmosphere, and the absorption of solar radiation and infrared from the earth all play fundamental roles in atmospheric energetics, as well as allowing a wide variety of remote sensing techniques. The NAS task group on atmospheric radiation recommended:

1) emphasis on theoretical investigations to test the sensitivity of climate models to uncertainties in the ability to handle the radiation part of the problem. Among the problems cited was the ability to consider real-world situations such as broken cloud fields.

2) development of improved optical, infrared, and sub-mm active and passive remote sensing instruments to monitor atmospheric parameters such as temperature, winds, trace gases, and humidity.

3) development of active and passive microwave sensors for satellite use to provide global monitoring of precipitation and soil moisture.

4) to monitor the spectral irradiance of the solar radiation reaching the earth.

Under (1) the task group emphasized the need for better models and for improved data on the radiative properties of clouds and collections of clouds. Atmospheric aerosols represent a research area where more information is needed, and another is the emissivity and absorptivity of the earth's surface as a function of season and location in all parts of the electromagnetic spectrum.

For remote sensing applications, the task group recommended a combination of ground-based and geostationary satellite remote sounding observations to provide continuous monitoring of temperature, moisture, wind-velocity structure, all at the subsynoptic scale. A combination of passive microwave imagers on

geostationary satellites and active microwave sensors on low-altitude satellites will open the possibility of global monitoring of rainfall distribution.

On the microscale, satellites can be used to gather, process, and communicate data from networks of unmanned sensors located in remote regions on the earth's surface, at sea, in aircraft, or on balloons. Such a data-gathering mission might not require a LARS system, but since we are talking about research data, it would certainly be appropriate and convenient to use a dedicated research satellite.

Dr. Weinman pointed out to us that from the standpoint of societal impacts, the priority research areas should be those that impact food production and energy consumption. For the first, primary needs are to monitor precipitation over wide geographical areas, and to improve understanding of precipitation processes. We also need a better understanding of soil moisture behavior as a function of location and season, and water evaporation at the earth's surface. To better handle problems of energy we need better seasonal forecasts, which implies better climate modeling along with improved data on influences such as sea surface temperature anomalies and ice coverage.

Better monitoring of precipitation from space platforms entails development of improved visual, infrared, and microwave techniques. Satellite borne active radar presents many technical problems but would be potentially very useful.

12) Solar Influences on the Earth's Atmosphere

John A. Eddy, National Center for Atmospheric Research,
High Altitude Observatory, Leader

Although the earth's upper atmosphere and magnetosphere are known to respond immediately and strongly to changes in solar output in those regions of the electromagnetic spectrum where solar radiation is highly variable (EUV and X-Ray), and evidence is convincing that the chemistry of the stratosphere responds to changes in the UV region, the response of the lower atmosphere is subtle, if it exists at all. The same remark applies to atmospheric response to streams of energetic solar particles: obvious changes in the high upper atmosphere as evidenced by aurorae and magnetic storms and substorms; subtle or non-existent response, except for changes in electrical conductivity and electric field patterns, in the lower atmosphere.

Investigations of the influence of solar variability on the lower atmosphere have been almost entirely in the form of searches for correlations between indicators of solar variability and parameters characterizing weather or climate. Very few suggestions have been made as to possible physical mechanisms and those that have been suggested have not been tied to the correlations that have been noted.

The NAS task group on solar influence notes that it is certainly time to stress physical coupling mechanisms and to de-emphasize the search for correlations. Theoretical and modeling analyses of possible physical links should point to the sorts of observations that could lead to advances in this research area. However, certain quantities obviously should be monitored:

1) The solar constant should be monitored to an accuracy of 0.1 per cent throughout at least one solar magnetic cycle (22 years).

2) The EUV and UV regions of the solar spectrum should be monitored to an accuracy of a few percent, since these wavelength regions play a determining role in the photochemical processes and temperature structure of the earth's upper atmosphere.

3) Solar wind structure at the earth, including its magnetic field, should be studied in detail, since many correlative studies appear to show statistical correlations between lower atmospheric dynamics (viz. vorticity) and magnetic sector boundary crossings at the earth. No physical mechanism has been suggested, and it may well be that the magnetic sectors are merely signals of solar variable phenomena and have in themselves no causal relationship to what has been observed.

4) High-energy particle fluxes: composition, energy spectra.

5) Global upper atmospheric electric current systems and auroral particle precipitation.

6) Global distribution of thunderstorms, electrical conductivity, electric currents and fields.

Although plans exist to monitor many of these quantities through the UARS Program, and other planned satellite programs, the key to understanding possible solar-troposphere couplings will come through the ability to look for specific predicted atmospheric responses: chemical, dynamic, meteorological, that are keyed to specific solar events. If such responses can be found, then the reliance on purely statistical correlations would be replaced by information relating to physical mechanisms, and the whole subject would suddenly be given a sound footing.

Dr. Eddy indicated to us that despite the great amount of effort at correlation between weather and climate events and solar phenomena, there still is nothing that is completely convincing. The most exciting recent development is the discovery of short term fluctuations in the total solar output. More research needs to be done before the reality of this phenomenon is firmly established, but if real it gives an important clue for a possible solar-troposphere coupling. In the LARS context there is clearly a high priority to be placed on continuous monitoring of the solar output to high precision, and there also would be advantages to looking toward the earth and toward the sun simultaneously to search for cause-and-effect patterns.

END